



# ***EXIST: Surveying the Obscured & Extreme Universe***

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## **Presentation to SEUS/Roadmap Committees**

**Josh Grindlay**

**Harvard**

(on behalf of the EXIST Science Working Group)

**December 3, 2001**

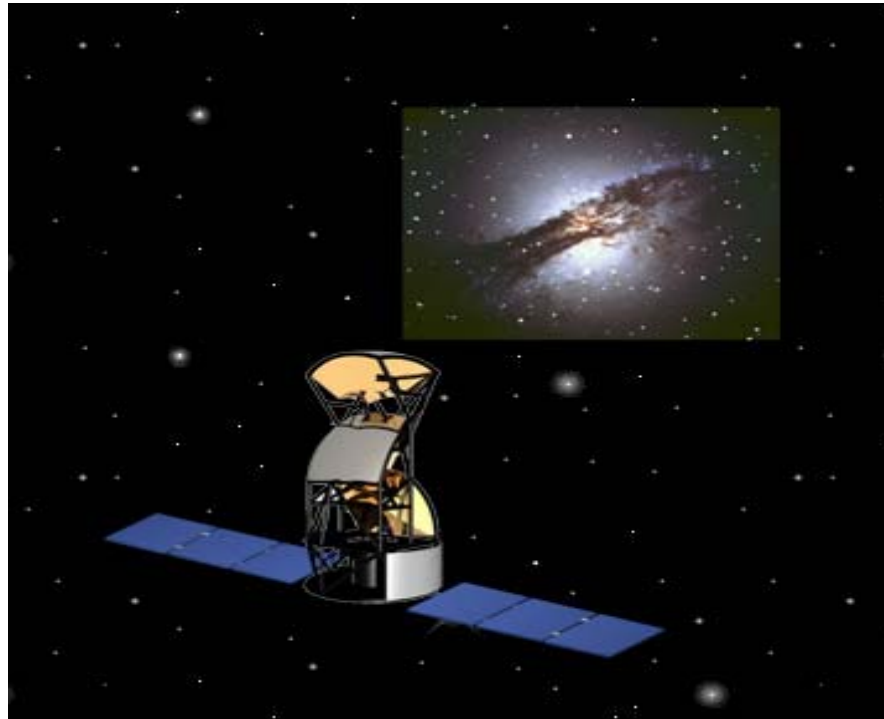


# Energetic X-ray Imaging Survey Telescope (EXIST)

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## Primary Mission Science Goals:

- Obscured AGN and accretion history of universe
- GRBs out to  $z \sim 20-30$  ( *$\sim 20X$  BATSE;  $\sim 5X$  Swift sensitivity*)



EXIST measures  
Cen-A every orbit:  
accretion efficiency  
and BH spin?

## Mission parameters:

- Extend ROSAT sens. ( $\sim 0.05\text{mCrab}$ ) to  $>100$  keV
- All-sky imaging ( $5'$  resolution;  $\sim 5-50''$  position) every 95min

<http://EXIST.gsfc.nasa.gov>

**EXIST**



# EXIST Overview

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## Mission Parameters (**low** -- **high** energy)

**Energy range (resolution):** **10-100 (1) keV**; **100 - 600 (3) keV**

**FOV & angular resolution:** **180° x 75°**; **5'**

**central-field for pointing:** **5° x 5°**; **50° x 40°**

**Sensitivity ( $5\sigma$ ):**

**(0.05mCrab=5x10<sup>-13</sup>cgs)**

**2mCrab --> 20mCrab/orbit**

**0.05mCrab --> 0.5mCrab/year**

**Temporal resolution:**

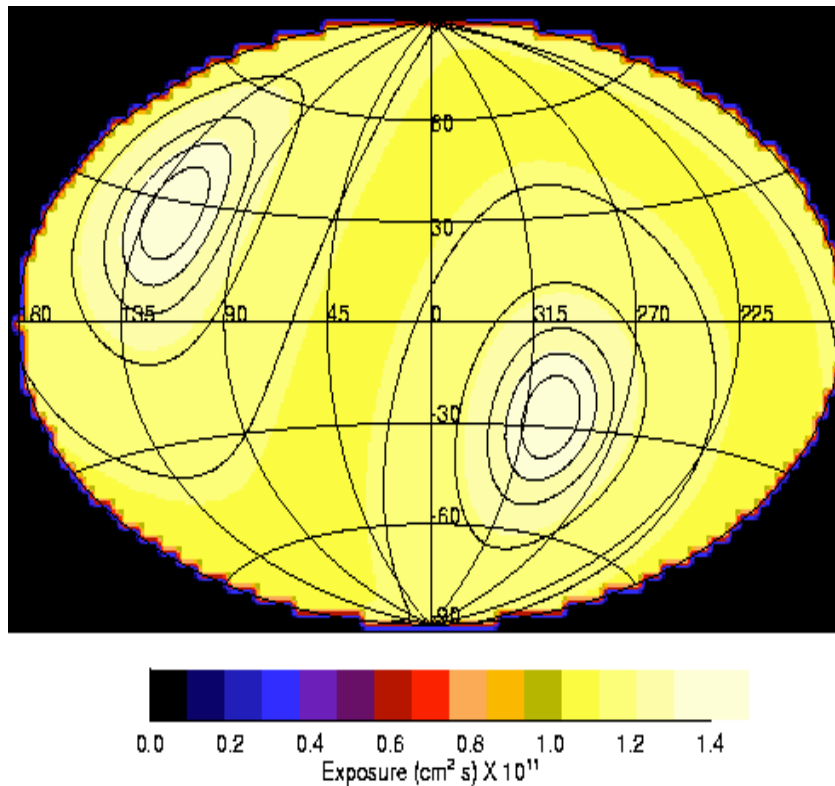
**1μsec --> ~30min; 95min --> 1 year**

**Telescopes/detectors:**

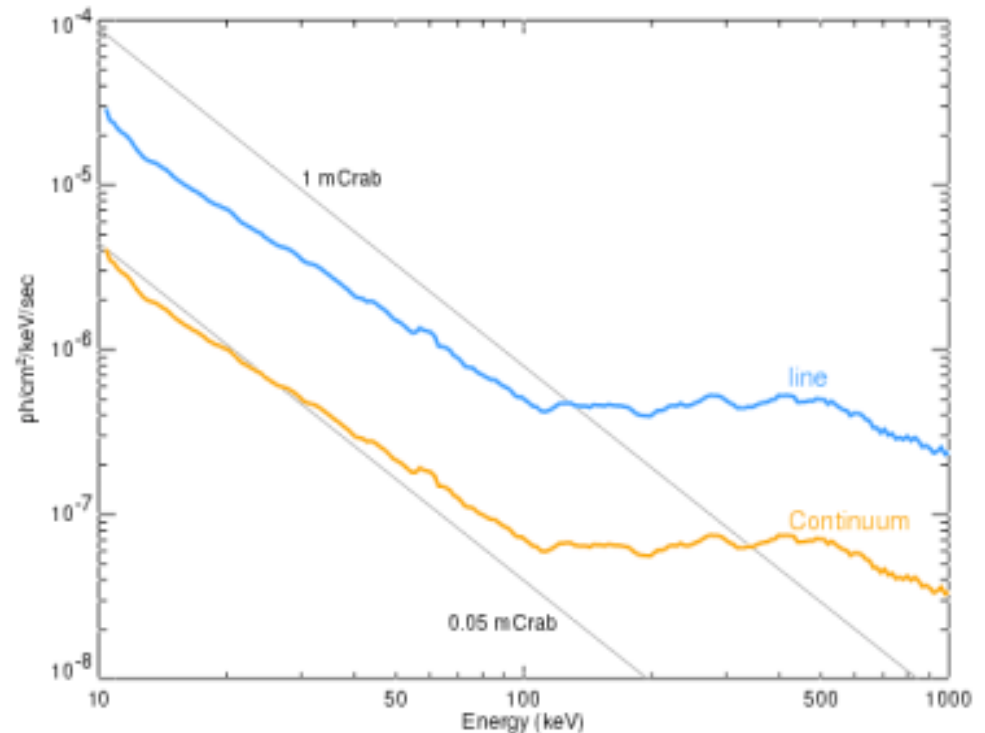
**coded aperture/8m\_ CZT (1.2mm pix)**



# EXIST Survey Exposure & Sensitivities



Exposure uniformity (galactic coords.)  
each day (increased exp. at orbital poles)

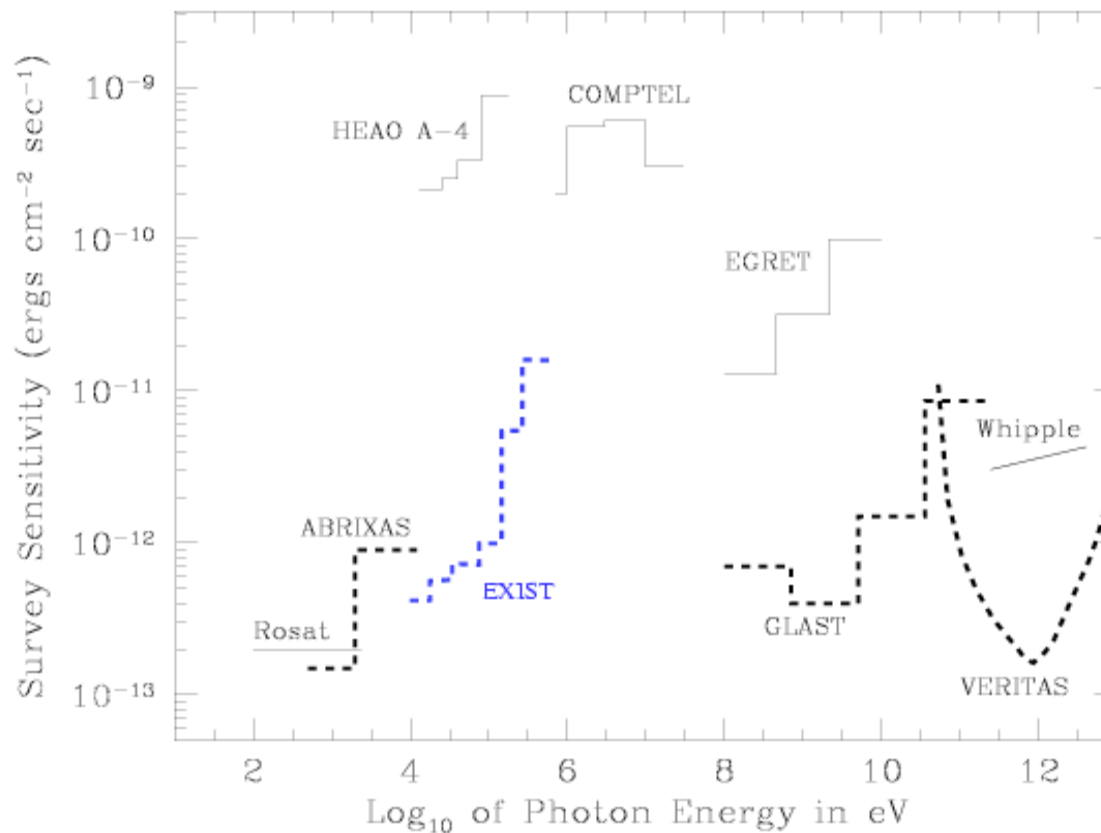


Continuum and line sensitivities ( $3\sigma$ )  
(~6-12mo. Survey; dep. on orb. lat.)



## Comparison with other Surveys

**EXIST** will extend **ROSAT** (soft x-ray) and complement **GLAST** ( $\gamma$ -ray)  
all sky imaging surveys:



(~6-12 month EXIST Survey sensitivity)



# GRB Mission Timelines

CGRO

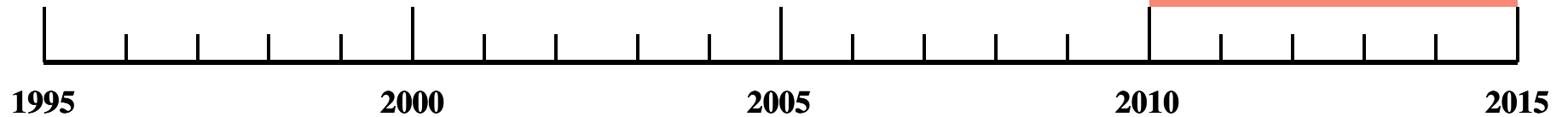
Beppo SAX

HETE - II

Swift

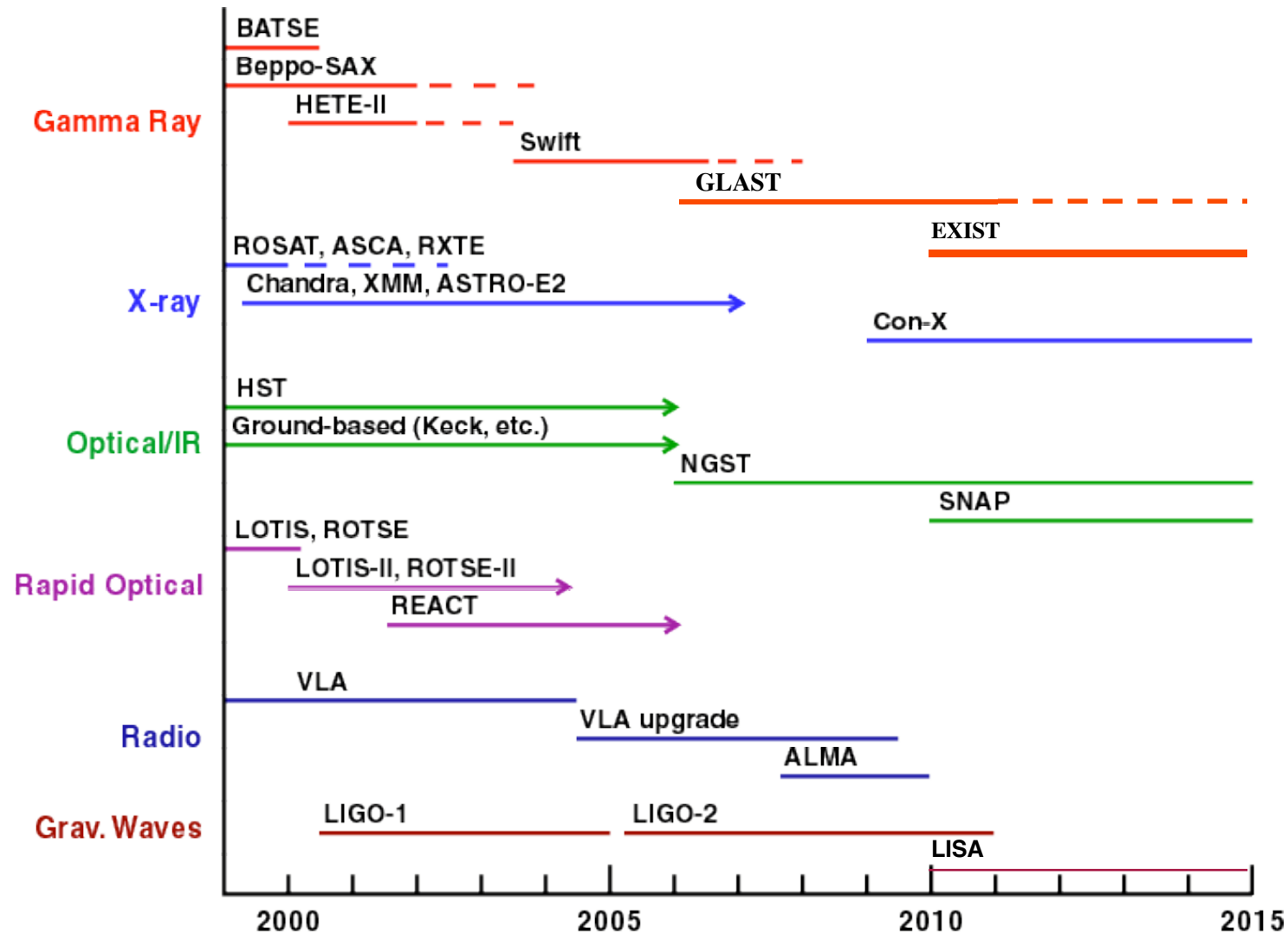
GLAST

EXIST





# Observatory Timelines

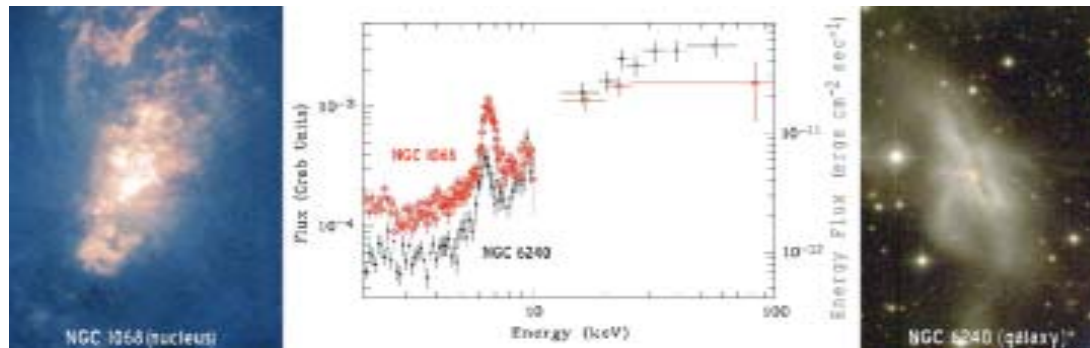




## Science Overview (Extragalactic)

*First all-sky (every orbit) imaging and variability hard x-ray survey*

- **Gamma-ray Bursts at the limit: Star Formation Rate to  $z \sim 30$ (?!)**
  - Highest spectral/temporal resolution images of GRBs (and SGRs)
- **Survey Black Holes on All Scales; Hard X-ray Background**
  - Obscured AGN: Accretion History of the Universe



Hard x-ray (HX) spectra (BeppoSAX) of heavily absorbed Seyfert 2 galaxies obscured by dust: hard x-rays penetrate the veil.

- Spectra of Seyfert II's and Type II QSOs: Contribution to HX Background
- **Diffuse IR Background**
  - HX spectra of Blazars simultaneous with GLAST/VERITAS





## Science Overview (Galactic)

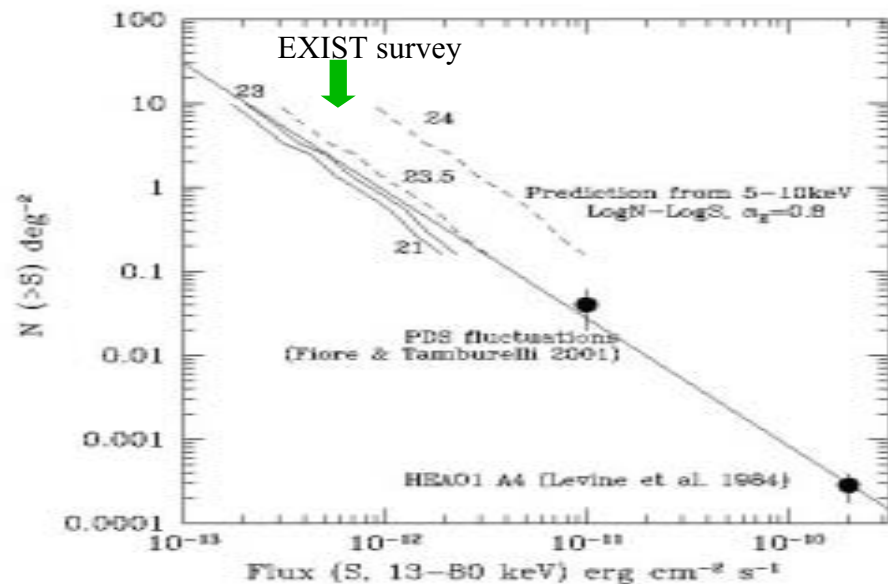
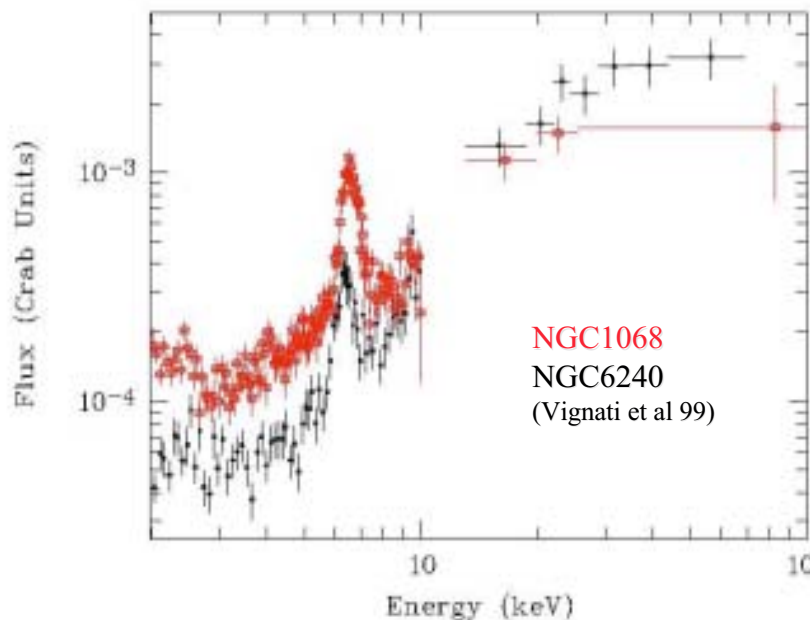
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- **Accretion onto Black Holes vs. Neutron Stars**
  - **Spectra and variability (QPOs):** *M/R & spin of BHs vs. NSs*  
(Pointed observations (5° FOV) have >30X statistics of RXTE at >20keV)
  - **Survey for persistent HX sources in GMCs:** *~10-100 Msun BHs or VMOs?*
  - **Survey for transients:** *neutron star vs. BH content of Galaxy; Local Group(!)*
- **Magnetic Fields of Neutron Stars**
  - **Cyclotron lines in LMXBs vs. HMXBs:** *magnetic field decay?*
  - **Soft Gamma Ray Repeaters (SGRs):** *SGRs in Local Group (to Virgo!)*
- **Supernova and Nova Rates in Galaxy: Stellar Death Rates**
  - **First map of entire Galaxy in 68,78 keV lines of  $^{44}\text{Ti}$ :** *hidden SNR*
  - **All sky monitoring/imaging of 478,511 keV fast (~8h) line transients:** *nova rate*



## Key EXIST science: Obscured AGN

**ASCA** and **BeppoSAX** find highly absorbed Seyfert 2's and likely dominant contribution of absorbed AGN to cosmic x-ray background:



and **Chandra** deep surveys find blank field and optically-dull AGN

➡ **EXIST** will find  $>1-10$  obscured AGN/square degree and obtain first all-sky measure of Seyfert 2 --> QSO 2 luminosity function



## Obscured BHs: *L<sub>acc</sub>*, Galaxies, and BH Spin

### Obscured AGN and HX background:

***L<sub>acc</sub>* > 0.1 L<sub>stars</sub>** since >85% of XRB from obscured AGN and  
observed  $M_{\text{BH}} \propto V^4$  is predicted (Fabian et al)  
➡ obscured BHs drive galaxy formation

***ε<sub>acc</sub>* > 0.15** from local (HST) mass density of BHs  
➡ Kerr BHs (spin)? Constrain from dL/dt

***XRB<sub>max</sub>* ~30keV** ➡  $z < 2$  for most XRB (Compton-thick Syll)

**EXIST** all-sky survey needed for Compton-thick  
AGN to measure distributions in  $z$ ,  $N_{\text{H}}$ , dL/dt

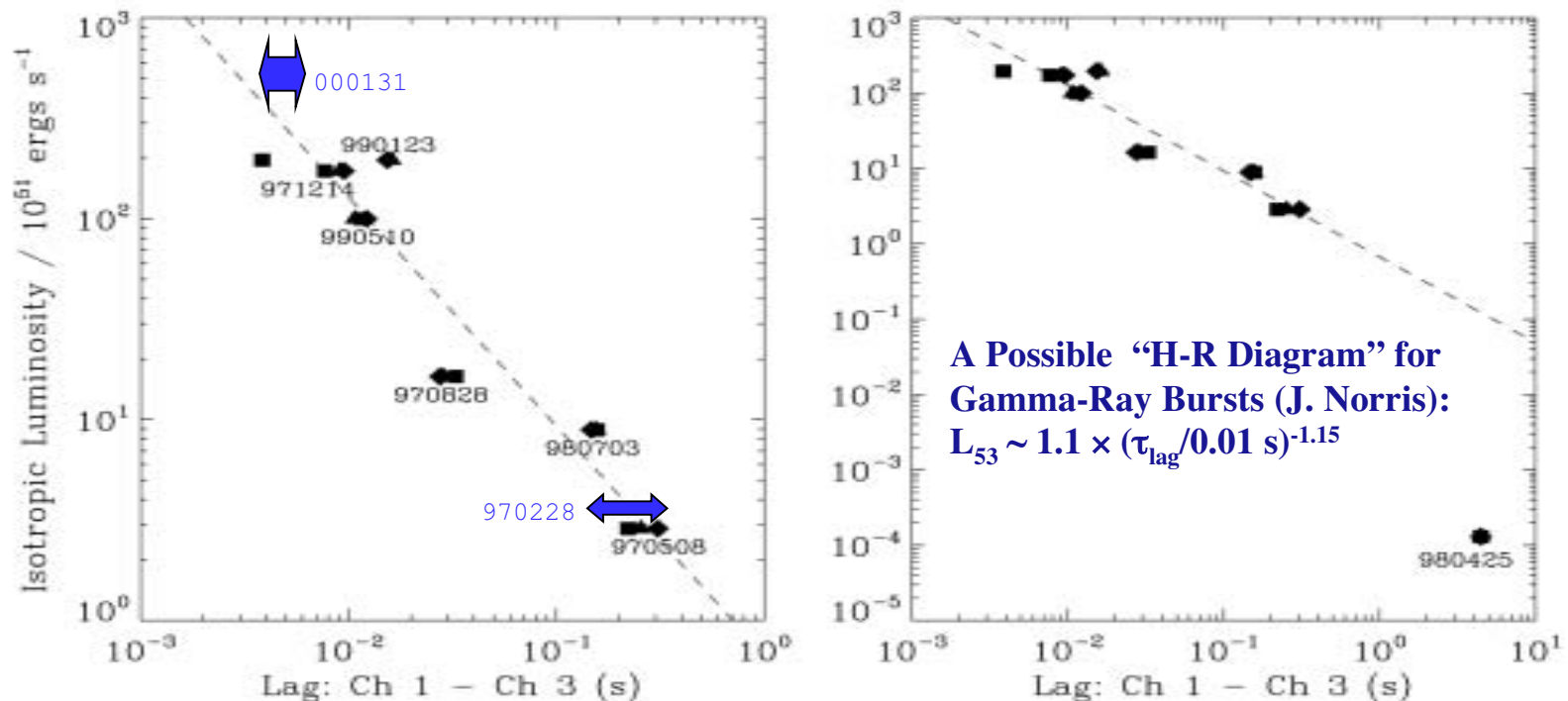
**EXIST**



# Next Generation GRB Observatory

**GRBs** have peak flux at  $\sim 100\text{-}300$  keV but extend to  $\gg 500$  keV.

- High time resolution spectra constrain source models & beaming
- Broad band spectral **lags** can constrain  $z$  (“photometric” redshifts):



**EXIST** will measure faintest GRBs over broadest spectral-temporal range  
 (2-3 GRBs/day; 5-50” positions) as primary component & **trigger** of a  
**Next Generation GRB Observatory**

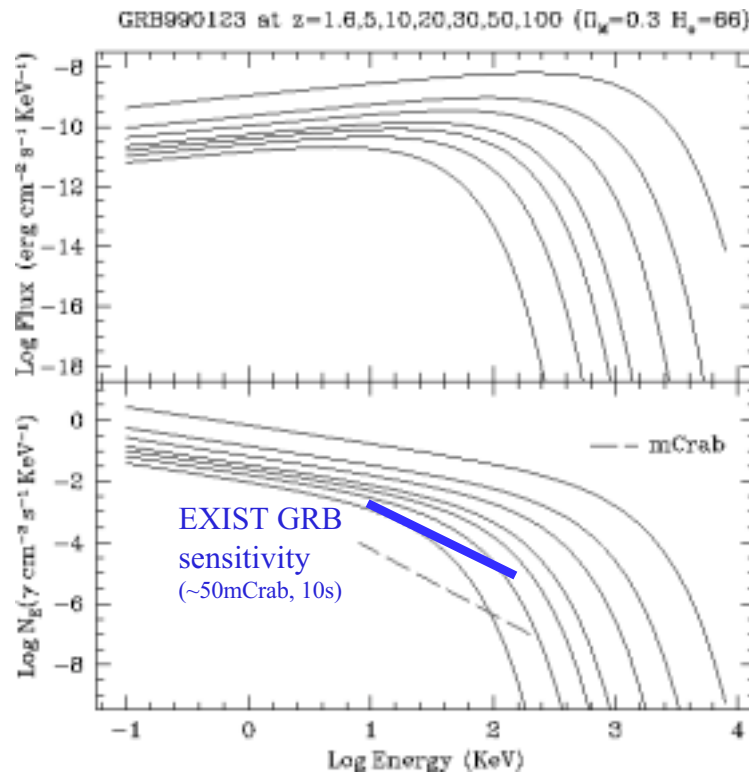
**EXIST**



## GRBs as Probe of Pop III and SFR at $z \sim 5-50$

“Long”-GRBs are likely from collapsars (BH formation)

$\sim 100 M_{\odot}$  stars likely as first (Pop III) stars  $\longrightarrow$  GRBs!



EXIST could detect  
bright GRBs to  $z \sim 50$   
and BATSE -threshold  
GRBs to  $z \sim 5$ .

Response to  $E > 100 \text{ keV}$   
needed even for  $z \sim 10$ !



## Comparison of EXIST vs. Swift

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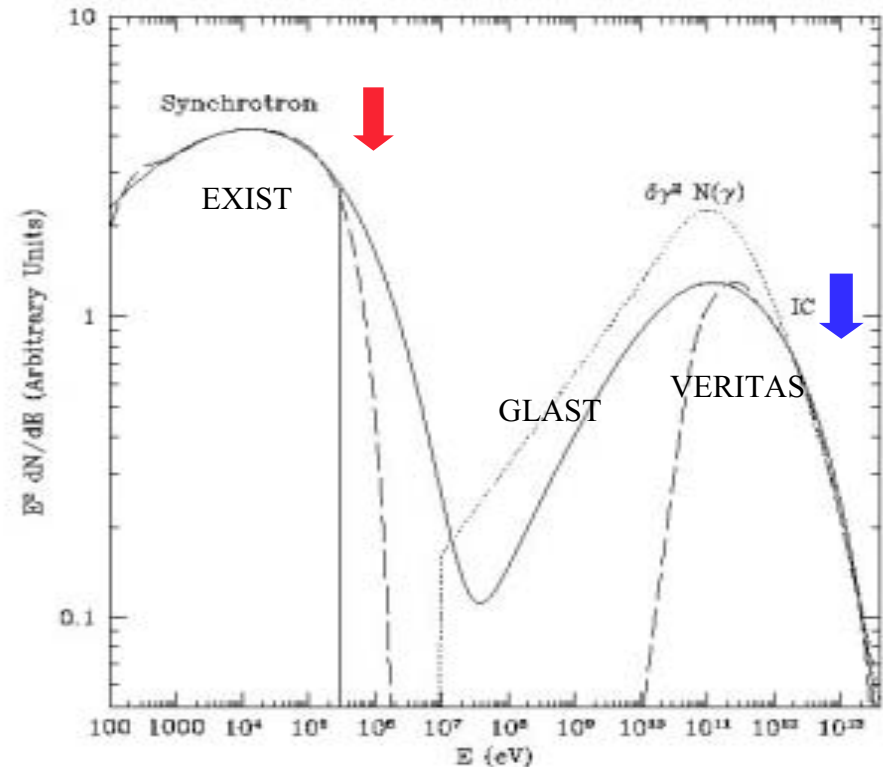
<u>Parameter</u>	<u>EXIST</u>	<u>Swift/BAT</u>
Energy range	10-600 keV	15-150 keV
FOV (instantaneous)	5sr ( $180^\circ \times 75^\circ$ )	2sr
CZT area (thickness)	8m_ (10mm)	0.5m_ (2mm)
GRB sensitivity	~20X BATSE	~5X BATSE
Full sky imaging	each orbit (95min)	~1month(?)
Angular res./loc.	5' / <10-50''	22' / <4'



## Key Science: Blazars and Cosmic Diffuse IR

**EXIST** provides broad-band imaging and monitoring of all AGN classes, including Blazars. Hard x-ray (synchrotron) spectral **breaks** ( $\sim 10$ - $200$  keV) allow gamma-ray ( $\sim 10$  GeV -  $10$  TeV) spectral **breaks** measured by **GLAST** and **VERITAS** to constrain origin of diffuse IR background for Blazars at known redshift (gamma-rays pair-produce on the IR background photons).

Time-variable intrinsic spectral breaks *required* from HX measurements.



SSC model for Mkn 501 (Coppi & Aharonian 99)

**EXIST will provide the continuous HX spectral-monitoring to study Blazars and non-thermal AGN as well as enable constraints on diffuse IR ( $\sim 10$ - $100$   $\mu$ ) background from obscured AGN**

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# EXIST Requirements

## Science Requirements

- High sensitivity: extend ROSAT/ABRIXAS survey ( $\sim 0.05$  mCrab sens.) to HX band
- Moderate imaging resolution ( $5'$ ): resolve AGN & centroid positions to  $\sim 5''$ - $1'$
- Broad energy band: from Compton bump (10 keV) to positron annihilation (511 keV)
- Moderately high spectral resolution: resolve 68,78 keV Ti lines; cyclotron line shapes

## Instrument Requirements

- Very large area, FOV and exposure coverage
- Coded aperture imaging over broad band
- Telescope aspect ( $\sim 5''$ ); zenith or inertial pointing

## Implementation

- $\sim 8$  m<sup>2</sup> imaging Cd-Zn-Te (CZT) detector array (10 - 600 keV)
- $180^\circ \times 75^\circ$  instantaneous FOV from 3 telescopes ( $60^\circ \times 75^\circ$ )
- zenith (and/or inertial) pointing, scanning entire sky each orbit





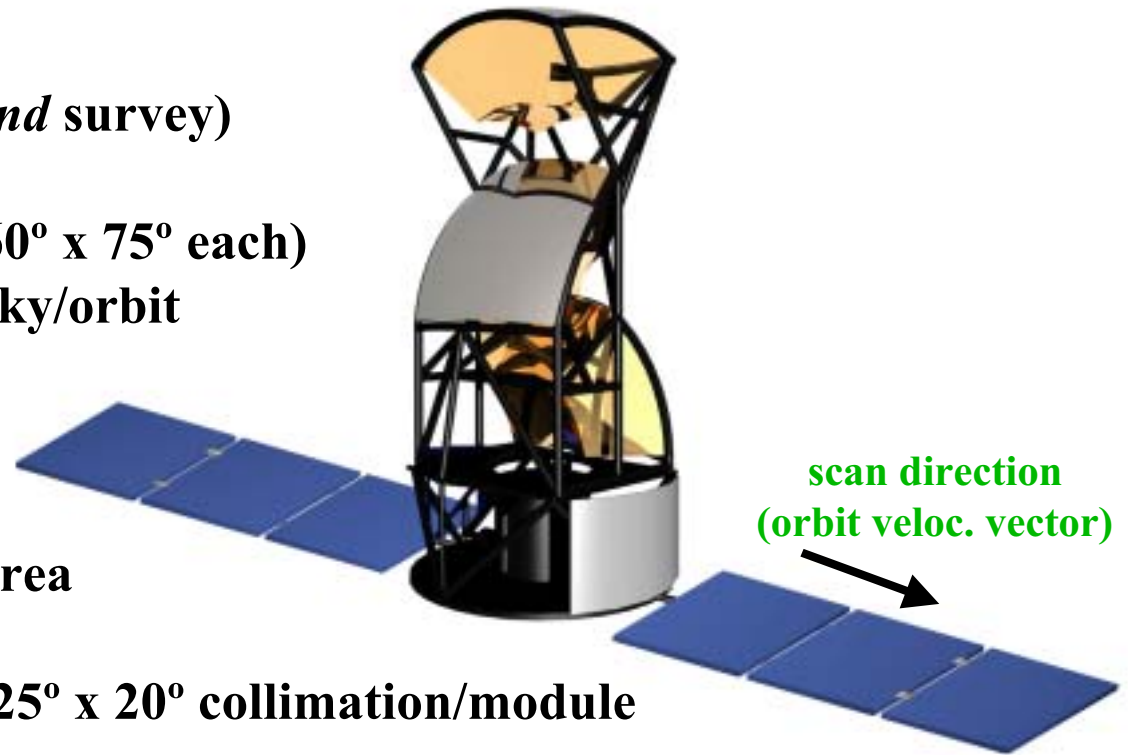
# EXIST Mission Concept

## *Free-Flyer (500km, $i \sim 20^\circ$ ):*

- Zenith pointer (Survey mode)
- 3-axis pointer (Observatory *and* survey)
- 3 coded aperture telescopes ( $60^\circ \times 75^\circ$  each)
  - ➔  $180^\circ \times 75^\circ$  fan-beam: all sky/orbit

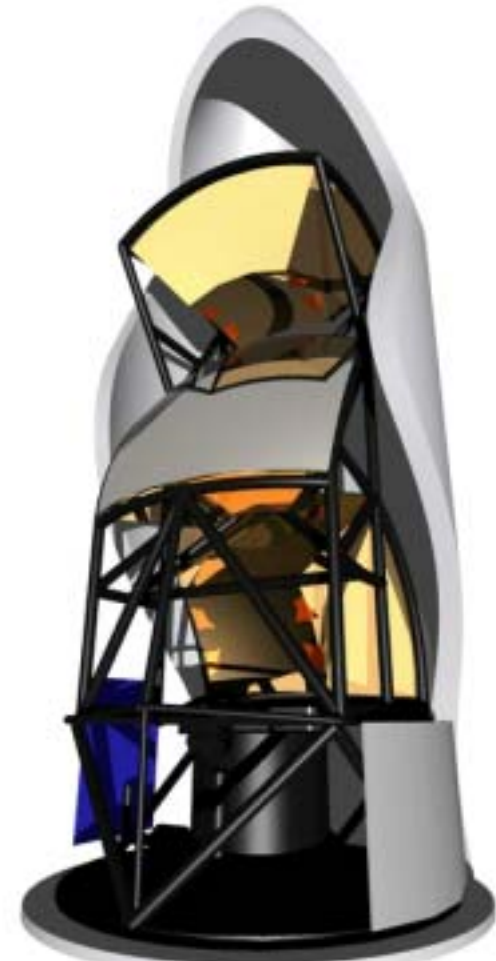
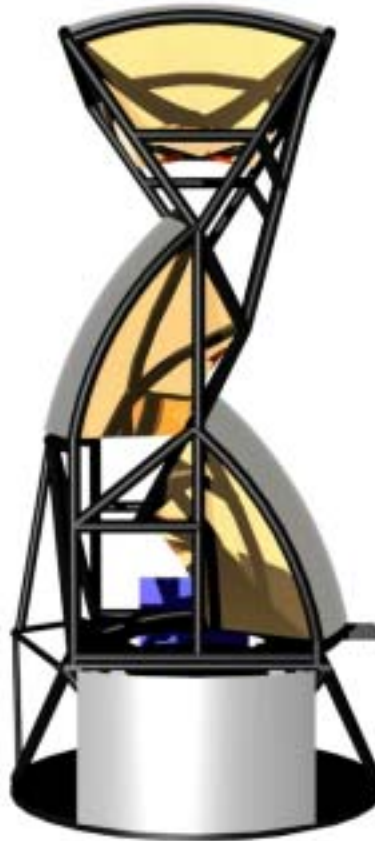
## *Mission Parameters:*

- CZT tiled arrays: 8m\_ total area
- Passive and active shielding;  $25^\circ \times 20^\circ$  collimation/module
- Mass, power, telemetry: 8500kg, 1200W, 1.2mbs (X-band)
- Delta-IV launch





# EXIST Telescope & Mission Design



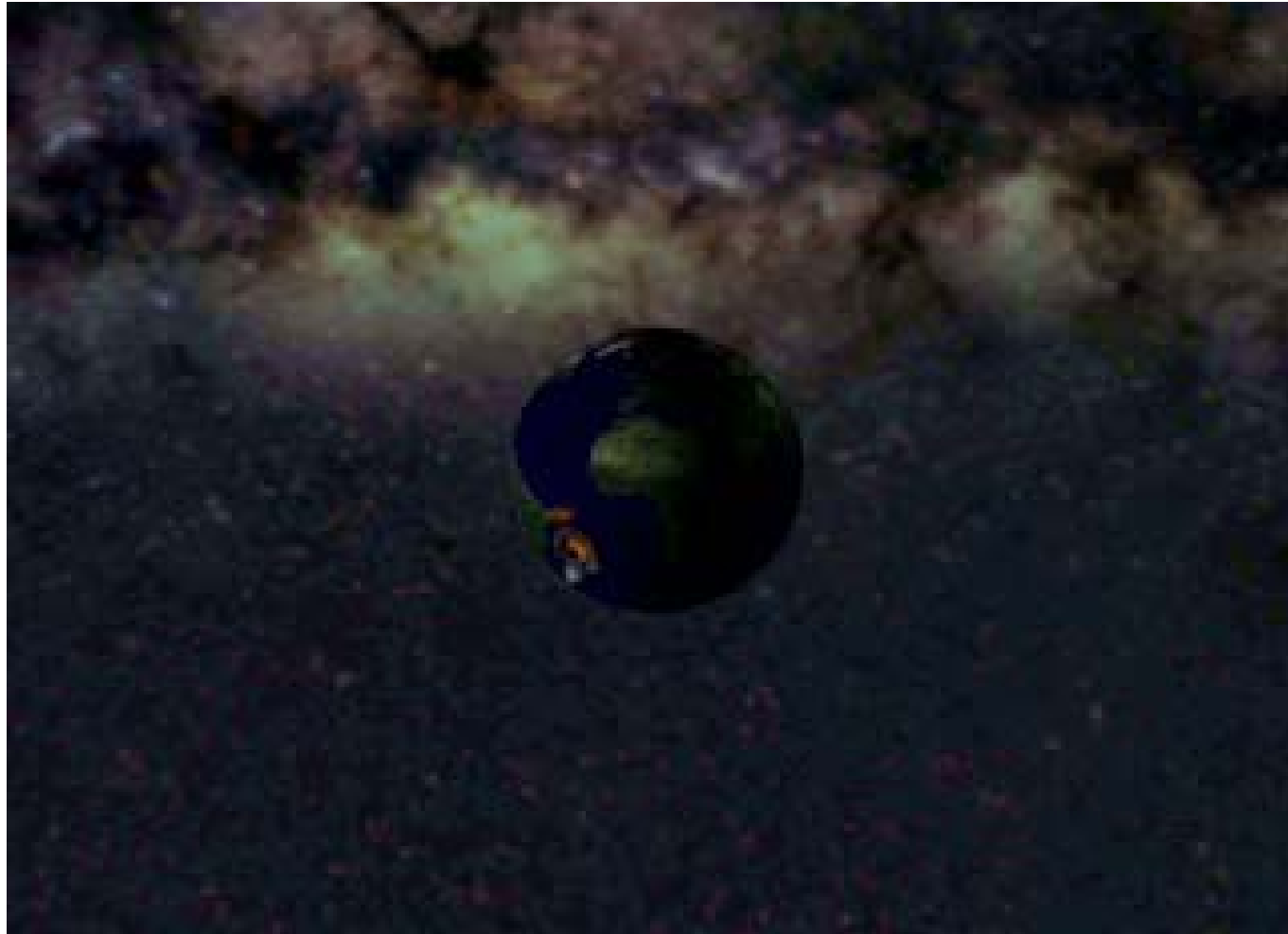
**Detector-collimator & Telescope views**  
(3 Telescopes + S/C: Ht x Diam ~8.6m x 4.7m)

**EXIST in Delta-IV shroud**



# EXIST Sky Coverage

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**FOV and survey coverage**  
(shown for Observatory pointing mode: target at orbital pole)



# EXIST Technology

## *Imaging and detector technology development*

- **Coded aperture hard x-ray imaging**

- Developed on SR&T/balloon payloads
- Demonstrated in space on SIGMA/GRANAT

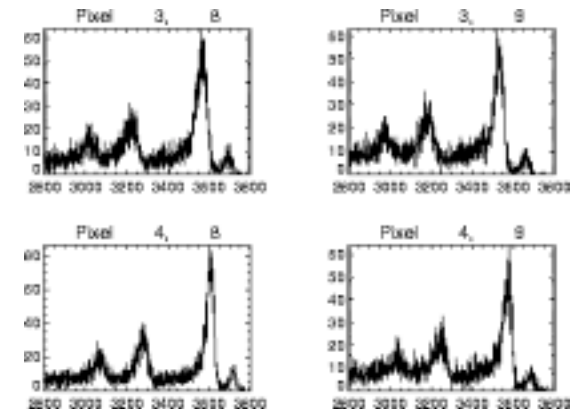
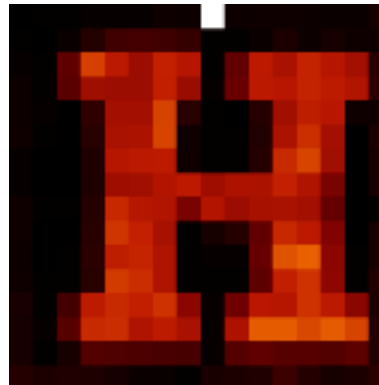
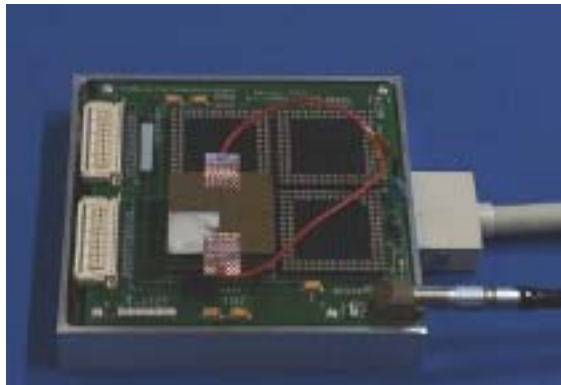
- **Cd-Zn-Te (CZT) detectors**

- Backgrounds measured & CZT imagers for balloons
- Large-area (0.5m<sup>2</sup>) CZT array to be flown on Swift (2003)
- Medical x-ray imaging lowering CZT imager costs



EXITE coded aperture telescope  
(20-600 keV) in balloon gondola

- **CZT imagers for 10-600 keV: 64cm<sup>2</sup> module, partial image & Ba-133 spectra  
(lines at 276, 302, 356, 383keV)**




**EXIST**



# EXIST Technology Roadmap

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	<u>Completion</u>
• <b>GSFC Mission Studies</b>	
– Instrument Studies Analysis Lab (ISAL)	2000
– Integrated Mission Design Center (IMDC)	2001
• <b>ASIC prototypes</b>	
- Low noise ( $\sim 1\text{keV}$ ) and power ( $0.1\text{mW/ch}$ ) for CZT array	2001
- Depth-sensing & multi-pixel readout incorporated	2002
• <b>CZT Detector module (HE and LE) development</b>	
- Basic CZT imager technology near ready to fly	2002
- CZT pixel-ASIC bonding and packaging	2003
- TRL4  TRL6 for CZT-ASIC-digital module	2004
• <b>Large area detector and shield prototype</b>	
- Balloon flight test of complete EXIST detector module	2005



# EXIST Heritage and Support

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- **Mission concept heritage**

- Selected as New Mission Concept (1994)
- GRAPWG Priority mission (1999)
- Formed Science Working Group (EXSWG) (1999)
- Identified Project Scientist & Project Formulation Manager (1999)
- *Recommended in NRC Decadal Survey as Medium Mission (2000)*
- GSFC/ISAL study of instrument concept for ISS (2000)
- GSFC/IMDC study for Free Flyer (2001)

- **Current support for EXIST**

- Partial CZT development support (~\$300K) under balloon-program SR&T grants
- Limited funding (\$70K) for initial GSFC/ISAL studies (2000, 2001)

- **Support needed for technology development/mission formulation**

- CZT - ASIC design optimization (for depth-sense sparse readout): ~\$1.5M
- Development of low-cost, high yield CZT-ASIC contacts: ~\$1M
- Development of shield design & detector-shield packaging: ~\$1M

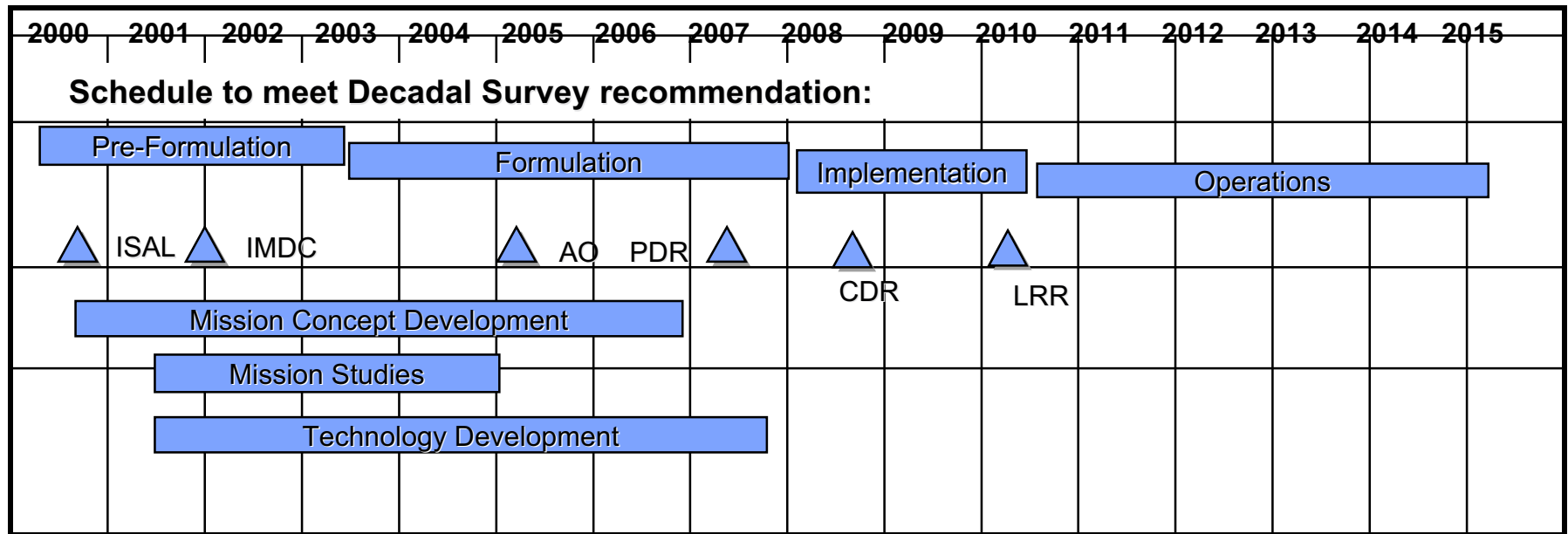
- **Estimated cost for EXIST mission (Free-Flyer) development & Ops**

- Total mission and ops (incl. GO prog.) cost ~\$350M (FY02\$)

**EXIST**



# EXIST Schedule



**EXIST *could* launch by 2010 and support GLAST, Con-X, NGST, LSST**





# EXIST Science Working Group (EXSWG)

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**EXSWG established with NASA concurrence in January, 2000**

Josh Grindlay (CfA/Harvard; Chair)

Lars Bildsten (ITP/UCSB)

Roger Blandford (Caltech)

Deepto Chakrabarty (MIT)

Andy Fabian (IOA, Cambridge, UK)

Fabrizio Fiore (Rome Obs./BeppoSAX, IT)

Jerry Fishman (MSFC)

Martin Elvis (CfA/SAO)

Neil Gehrels (GSFC; Study Scientist)

Chuck Hailey (Columbia Univ.)

Fiona Harrison (Caltech)

Dieter Hartmann (Clemson Univ.)

Chryssa Kouveliotou (MSFC)

Tom Prince (Caltech)

Brian Ramsey (MSFC)

Rick Rothschild (UCSD)

Gerry Skinner (CESR/Toulouse, FR)

Stan Woosley, (UC Santa Cruz)

**Project office (GSFC) established:**

Ruth Carter, Study Manager

***EXSWG and Discipline Teams to be expanded***





## EXIST Mission Collaboration(s)

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**Discussions ongoing with interested  
*International Partners*  
(possible mission hardware support):**

- Italy (Bologna, Rome; also ground station support)
- Germany (MPE, Univ. Tübingen)
- UK (Leicester, Southampton)
- Netherlands



# EXIST Summary

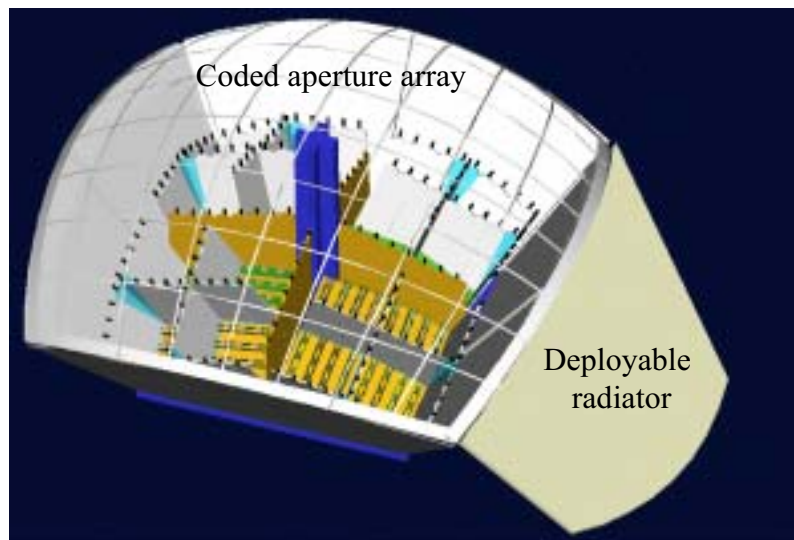
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- EXIST conducts *high priority science*
  - Highest sensitivity full-sky probe of obscured universe
  - Ultimate sensitivity broad-band, high resolution study of GRBs
  - Decadal Survey high ranking shows broad astrophysics interest
- Science highly *complementary to other OSS and ground-based missions*
  - Finds most luminous obscured AGN for study by Con-X, NGST
  - Hard x-ray all sky imaging/monitoring complements GLAST, LSST
- Technology *connects to OSS missions and industry*
  - CZT large area detectors developed for Swift and medical imaging
  - Extension to very large area using new techniques from GLAST & industry
- Mission accommodates *launch/operations for Free Flyer or ISS*
  - Large area/mass telescope with zenith scan and target pointing (EXIST-FF)



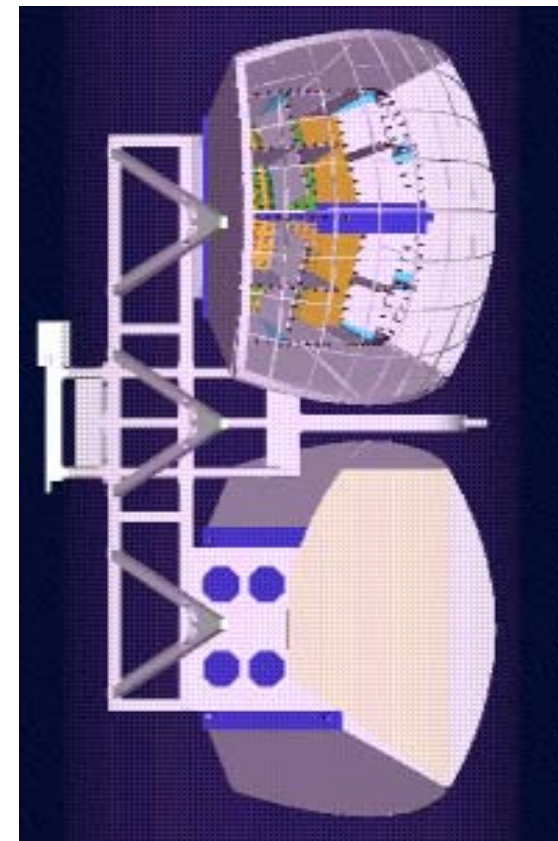
## EXIST-ISS Concept (Backup)

- 80° x 80° coded aperture telescopes (2) fixed on ISS Truss site(s)
- Detector plane is tiled CZT array; CsI collimation/shielding



One of 2 EXIST telescopes: 2 x 2 array of 40° telescopes for combined FOV of 160° x 80°. CZT detector array and CsI shields/collimator shown.

*Mount on ISS Truss (P3 or P3 + S3-inboard) with 160° FOV along Truss and most-sky each orbit*



Full EXIST payload in launch (STS) configuration.